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# White spruce Regeneration in Mixedwood Forests of the EMEND Project in the Northwest Boreal Region of Alberta 1999 – Update

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***Abstract:***

The objectives of the project were a) to test the growth response of white spruce seedlings to the microenvironment created by different mechanical site preparation treatments under different levels of residual canopy, b) to assess the receptivity and longevity of these microenvironments as seedbeds, c) to quantify white spruce cone crop production following release in the different harvesting treatments, and d) to monitor the white spruce seed rain into the study plots.

We set up study plots in three replicates of each of the six combinations of aspen-dominated (Adom) and conifer-dominated (Cdom) forest type, and harvest treatments of 0%, 50% and 75% canopy retention. Four subplots were established for mechanical site preparation treatments (control, mix, mound and scalp). Planting (415B white spruce) and seeding were carried out on these site preparation microsites. In the fall, 72 seedlings were harvested for biomass and nutrient analysis. Seed traps were placed at each subplot to measure seed rain. We made visual estimates of cone crop production in all Cdom compartments, and tested our rating system against binocular counts and counts from felled trees.

In one replicate of each forest type – harvest treatment combinations, we installed instruments to continuously monitor above- and below-ground microclimates of the four microsite types. We also made spot measurements to capture the spatial variation in air and soil temperatures.

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**Progress Report to the Manning Diversified Forest Products Research Trust Fund - 2000**
**White Spruce Regeneration in Mixedwood Forests of the EMEND Project**

Principal Investigator: Jim Stewart

## *Introduction*

The purpose of this project is to investigate the biological and physical processes that determine the regeneration of white spruce under different silvicultural systems in boreal mixedwood stands. It is of the larger EMEND project, which is an interdisciplinary experiment being carried out northwest of Peace River. The global objective of the EMEND project is to determine which forest harvest and regeneration practices best maintain biotic communities, spatial patterns of forest structure, and functional ecosystem integrity in comparison with mixedwood landscapes that have arisen through wildfire and other inherent natural disturbances.

*Effect of partial harvesting and mechanical site preparation on growth of planted stock*

White spruce regeneration following clear cut harvesting is often difficult and expensive (Navratil et al. 1991). We know that white spruce regenerates under aspen canopies at many stages of stand development (Lieffers et al. 1996). This observation suggests that understory regeneration may be a less risky and possibly less expensive alternative to a clear cut and plant regime. Underplanting trials indicate that nursery stock can establish and achieve good growth rates under aspen or mixedwood canopies (Day 1970, Lieffers and Stadt 1994). Under a closed aspen canopy, there was little difference in growth of planted seedlings among scalped, bedded, and untreated forest floor microsites (Stewart et al, in press). Under partial cut regimes, where more light is admitted to the forest floor and competition is expected to be greater, mechanical site preparation that reduces competition may produce a greater difference in growth response of the seedlings.

All of the studies mentioned above have examined the growth response of spruce seedlings to different overstory and forest floor conditions. However, little attention has been paid to the changes to the physical environment by the silvicultural treatments, and their subsequent effect on seedling physiology and the driving factors for growth. Only recently has silvicultural research begun to take a quantitative, process-based approach, such as the studies of light environments and seedling growth in natural undisturbed stands coming out of Vic Lieffers' lab (Lieffers and Stadt 1994; Man and Lieffers 1997). Such process studies are the building blocks for developing models of the effects of silvicultural practices. The models in turn allow us to extrapolate the results of studies more broadly, and to evaluate the potential outcomes of management practices before we carry them out. This type of ecophysiological research needs to be extended to different forest types and management regimes.

The objectives of this study are: a) to assess the effectiveness of blading, mixing, and mounding as silvicultural treatments to promote the establishment and growth of white spruce planted stock under different levels of residual canopy in aspen-dominated and white spruce-dominated stands, b) to quantify the influence of the harvest and site preparation treatments on the microenvironments of the seedlings, and c) to quantify the relationship between microenvironment and seedling physiology and growth.

*Effect of partial harvesting and mechanical site preparation on regeneration by seed*

In natural stand development, disturbances such as fire and windthrow create microsites that are more conducive to white spruce germination and establishment than undisturbed forest floor. White spruce seeds are 100 times more likely to establish and survive to four years of age on mineral soil than on undisturbed litter (Eis 1967). Rowe (1955) characterized the white spruce regeneration situation thusly:

> "spruce has its best possibilities for survival where conditions prevail which tend to prevent other plants from closing in and monopolizing moisture, light, and space. Such conditions generally exist on decayed wood and disturbed (i.e., scraped or severely burned) mineral soil."

Mechanically prepared planting spots can play the same role in white spruce regeneration from seed by emulating many of the properties of natural disturbance microsites.

In partial cutting trials in mixedwood stands, natural regeneration was adequate on plots scarified down to mineral soil regardless of cutting intensity, but was poor to non-existent on undisturbed microsites (Lees 1963, 1964, Stewart et al. unpublished). However, a regeneration survey excluding the scarified microsites showed that both seedling density and stocking were higher under the intermediate cut levels than in either uncut or clearcut stands (Lees 1964). Longevity of seedbeds was also examined in different studies, and appeared to be longer under partial canopies than in clear cuts (Lees 1963, 1970).

This project extends previous work by examining white spruce natural regeneration across a range of mixedwood composition (both aspen-dominated and spruce-dominated), with three types of mechanical site preparation, and examining seedbed receptivity across the range of residual canopy from clear cut to 75% residual.

The objectives of this study are: a) to assess the effectiveness of blading, mixing, and mounding as silvicultural treatments to promote the germination and survival of white spruce under different partial harvest regimes, b) to determine how long prepared seedbeds remain receptive to seed establishment under the different partial harvest regimes, and c) to measure the spatial and temporal variation in white spruce seed rain in different compositions of mixedwood forest.

*Development of cone crop potential following release*

Silviculture systems that seek to regenerate white spruce naturally will in many cases rely on seed-bearing spruce left within the stand. If dominant or codominant spruce trees are left in the residual stand, then adequate seed rain should result from as few as 15 seed trees per ha (Quaite 1956). However, if such trees do not occur in the stand or are removed because of susceptibility to windthrow, then maturing understory trees may be the best source of seed.

White spruce growing in more dominant positions are better seed producers than suppressed trees (Waldron 1965). This can be attributed to better light conditions, and possibly to a better water and nutrient supply, since large canopies are generally supported by large root systems. These factors are all important in determining the development of a cone crop (Owens and Blake 1985). Release from a surrounding canopy will increase the availability of these resources to the remaining trees, and should result in increased development of cone crops, as was observed in suppressed Norway spruce (Okishev and Pugachev 1983).

It is important for silvicultural planning to be able to estimate when seed-bearing capability will

develop, so that establishment microsites resulting from harvest disturbance or mechanical site preparation may be effectively utilized.

The objectives of this study are a) to quantify the development over time of cone crops on white spruce trees from different crown classes following various degrees of release in partial harvested mixedwood stands, and b) to develop efficient field methods for estimating the size of white spruce cone crops.

*Project objectives*

In summary, the objectives of the project are:

1. to assess the suitability for promoting growth of white spruce seedlings of different mechanical site preparation treatments under different levels of residual canopy,
2. to assess the receptivity and longevity of seedbeds created by mechanical site preparation under different residual canopy conditions,
3. to quantify the production of cone crops by white spruce in different canopy classes and exposures following release by the harvesting treatments, and
4. to monitor the white spruce seed rain into the silviculture plots.

## Methods

*Background on the EMEND project*

The EMEND experiment encompasses four forest types that represent four stages in the main successional pathway for western boreal mixedwood forests: aspen-dominated, aspen-dominated with white spruce understory, aspen-spruce mixedwood, and conifer-dominated. Three replicates of each forest type were identified, and each replicate was composed of one or more stands. Each replicate forest type was divided into 10 ha compartments to which the different harvest treatments were assigned (Fig. 1).

The harvest treatments were clearcut (or 0% residual), 10%, 20%, 50%, and 75% residual partial cutting, and an uncut control. Medium and low burn treatments were assigned to each replicate, and a high burn treatment was established in one replicate of each forest type. All felling operations were carried out from designated machine corridors 5 m wide and spaced 20 m apart centre to centre. All trees were removed from the machine corridors representing a removal of 25%. For the 10%, 20% and 50% residual treatments, trees were removed from the leave strips by reaching in to achieve the final stand-level prescription (Fig 2). Two elliptical leave patches were left undisturbed in each compartment (Fig. 3). All skidding was done from the machine corridors, except in clearcuts where skidding was random.

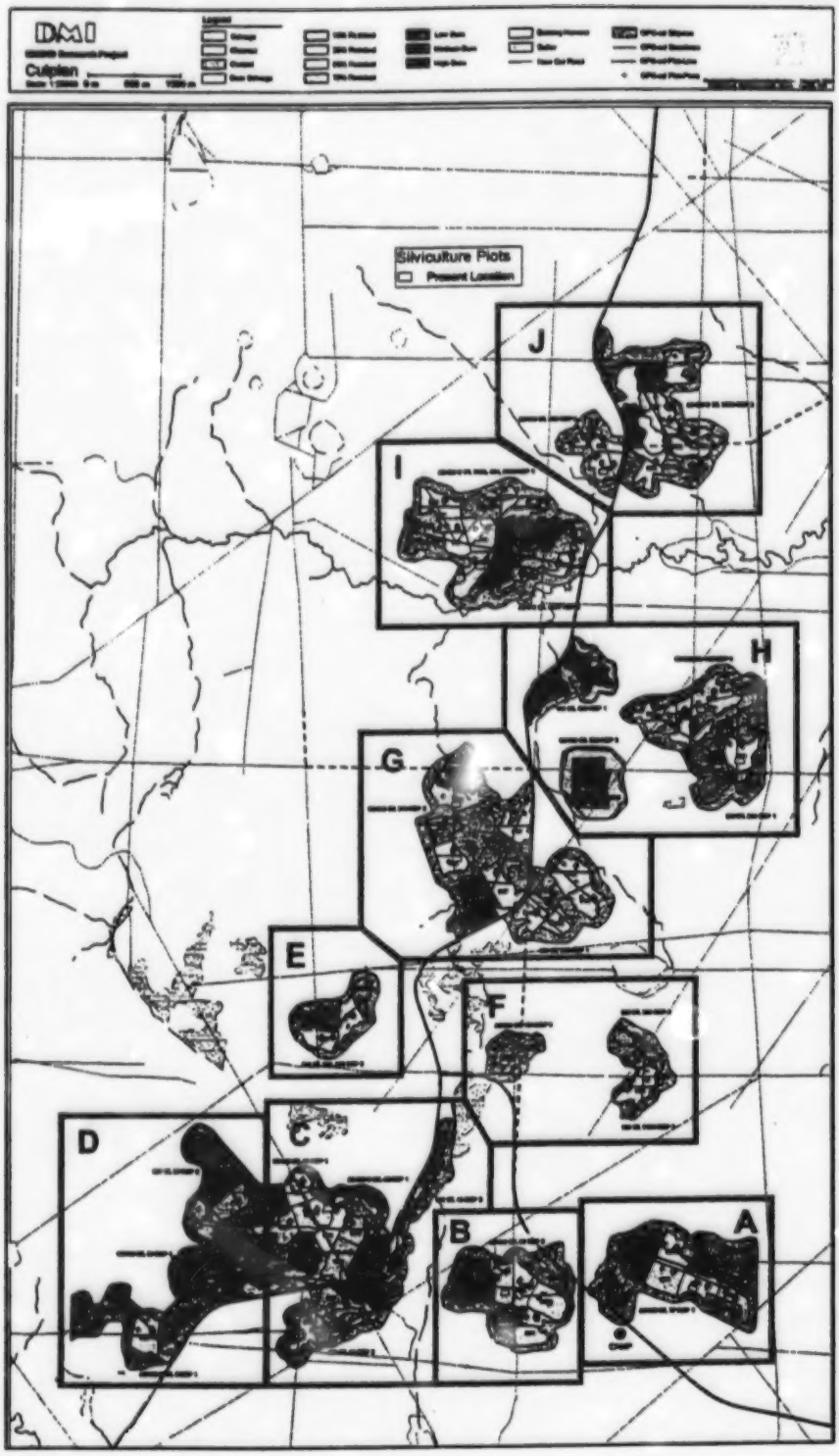


Figure 1. Map of the EMEND experimental site.

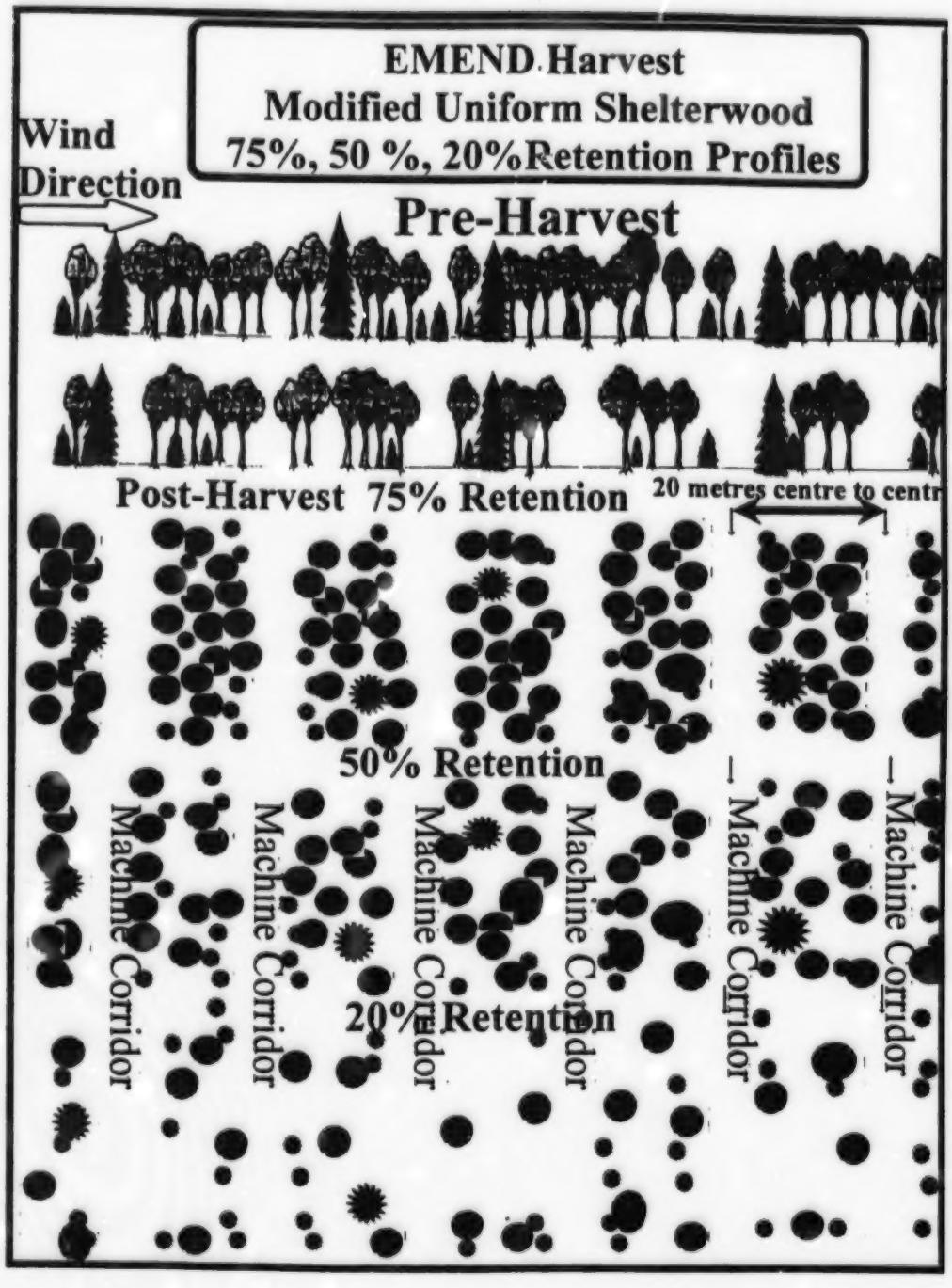


Figure 2. Plan and elevation views of the harvesting patterns used in the EMEND partial cut treatments.

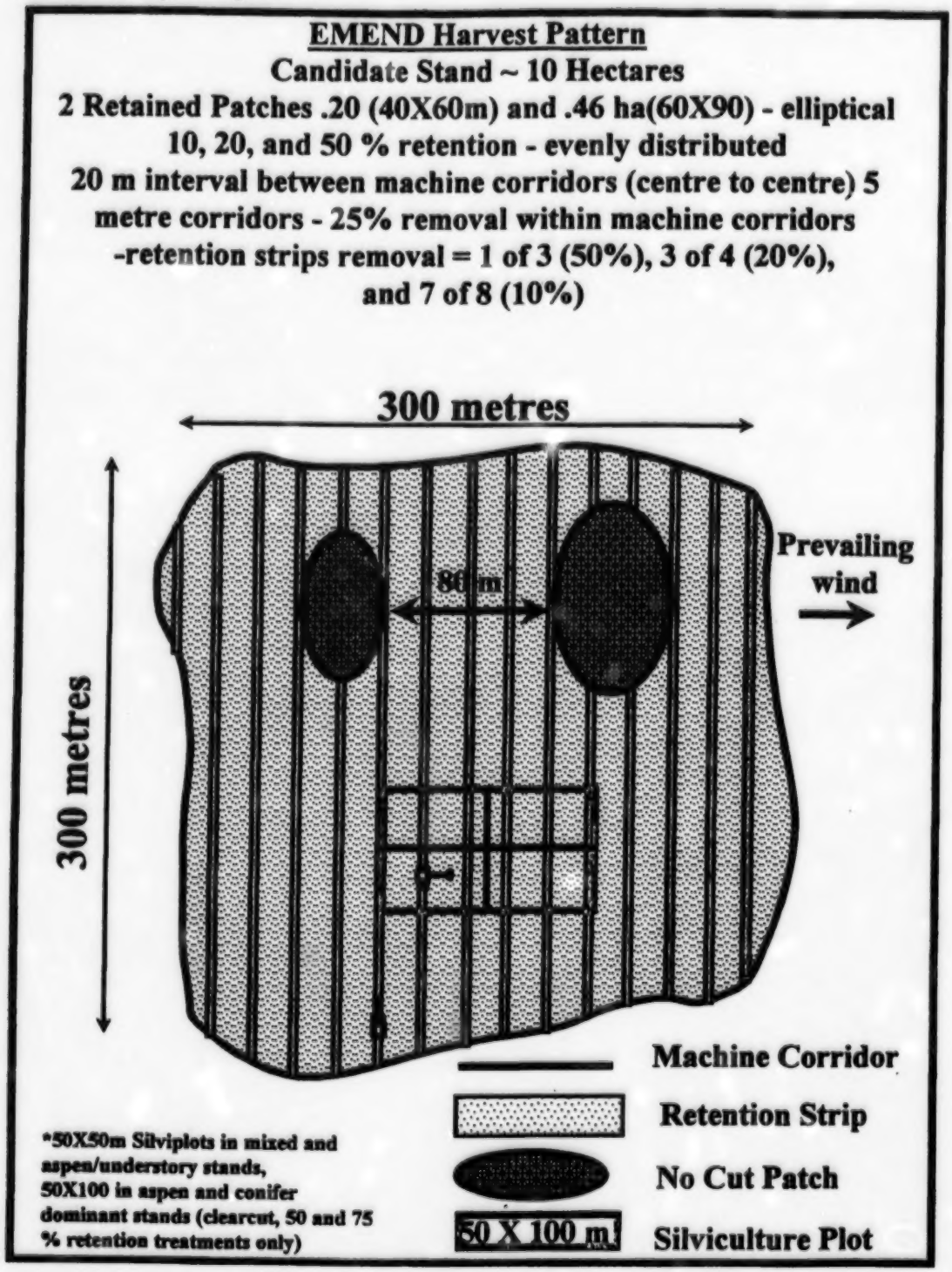
EMEND Harvest Pattern
Candidate Stand ~ 10 Hectares
2 Retained Patches .20 (40X60m) and .46 ha(60X90) - elliptical
10, 20, and 50 % retention - evenly distributed
20 m interval between machine corridors (centre to centre) 5 metre corridors - 25% removal within machine corridors
-retention strips removal = 1 of 3 (50%), 3 of 4 (20%), and 7 of 8 (10%)
300 metres
300 metres
80 m
Prevailing wind
*50X50m Silviplots in mixed and aspen/understory stands, 50X100 in aspen and conifer dominant stands (clearcut, 50 and 75 % retention treatments only)
Machine Corridor
Retention Strip
No Cut Patch
50 X 100 m
Silviculture Plot

Figure 3. Generalized layout of harvest treatment compartments at EMEND. Note the placement of the elliptical leave patches and the rectangular silviculture plot. Landings were located along the south edge of the compartments.

*Effect of partial harvesting and mechanical site preparation on growth of planted stock*

In collaboration with Derek Sidders (CFS) and TimVinge (CanFor), we established the study sites for this project in 0.5-ha silviculture plots (Fig. 3) located in all three replicates of the aspen-dominated and white spruce-dominated forest types, in those compartments with 0% (clearcut), 50% and 75% residual density. These "silviculture" plots were situated to minimize effects of proximity to the compartment edges and to the elliptical leave patches. As only one prescribed burn was carried out this year, no plots were established in burn compartments.

The silviculture plots were divided into equal quadrants, and one of four site preparation treatments was assigned at random to each quadrant (Fig. 4). The plots will be divided into 4 quadrants to accommodate the prescribed microsite treatments (scalp, mound, mix and untreated control; Fig. 5). Microsites were prepared using a 200 series excavator as prime mover and two attachments, a mounding bucket for the scalp and mound treatments and a Meri-Crusher high-speed horizontal drum mulcher for the mixing treatment. Approximately 200 microsites were prescribed per treatment. However, in some of the site preparation plots the full complement of microsites was not achieved, particularly in the 75% residual stands and with the scrape treatment which occupied the most area per microsite.

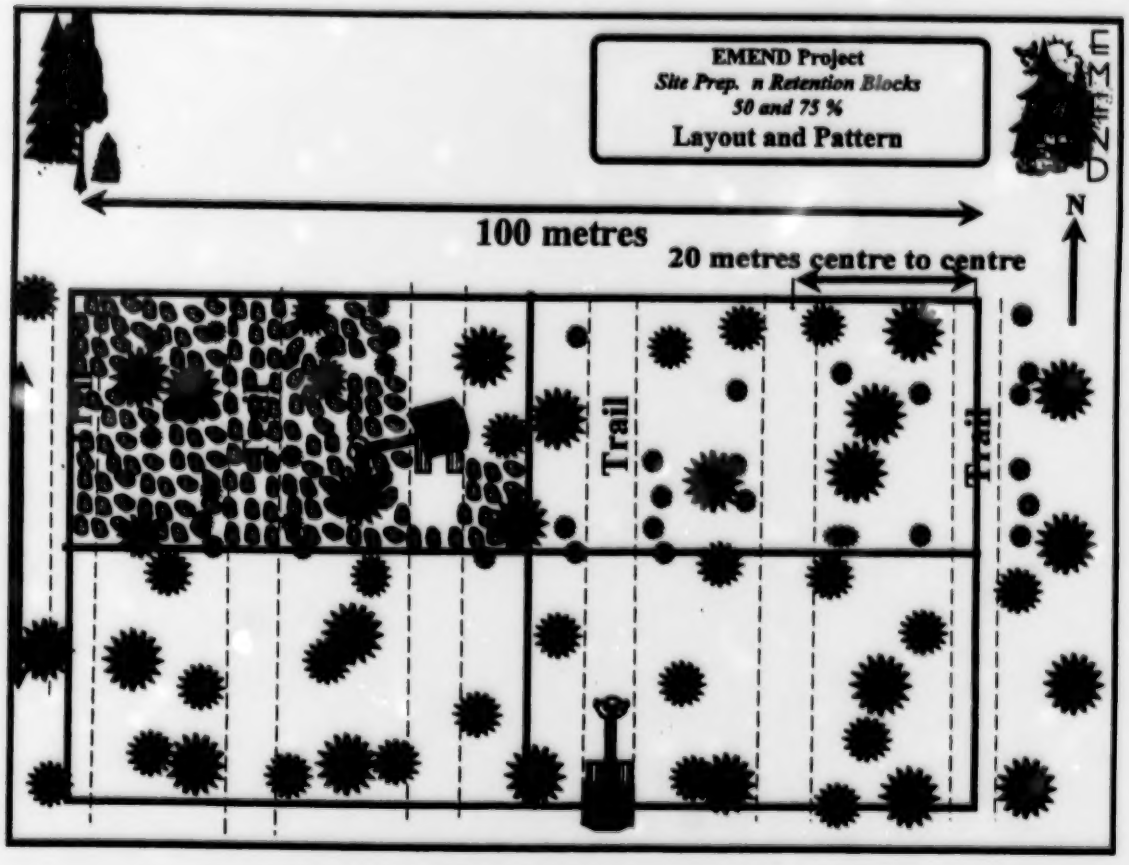


Figure 4. Layout of the silviculture plots indicating the quadrants assigned to the different mechanical site preparation treatments.

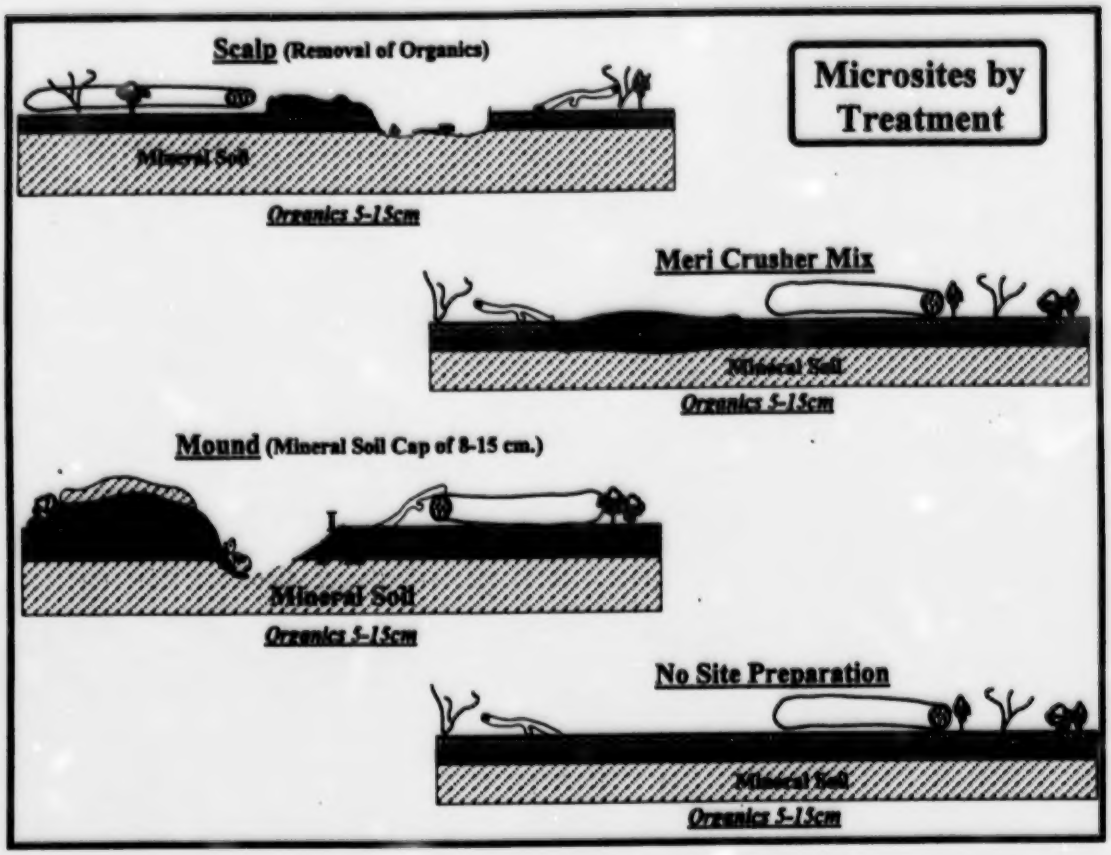


Figure 5. Generalized profiles of microsite created by the different mechanical site preparation treatments used at EMEND.

In each quadrant, 100 microsites were pinned and tagged for planting, and the seedlings (415B white spruce stock) for long-term monitoring were planted in July. Ten additional seedlings per treatment plot (from the same stock) were planted in early August to be used for physiological and other studies requiring destructive sampling.

A subsample of the physiology seedlings was harvested in September 1999 for measurement of biomass partitioning to needles, stems and roots. Nutrient contents of the needles were analyzed in the lab.

Measurements of seedling photosynthesis and water status will begin in June 2000 as the seedlings grow and respond to the planting environments.

Microenvironment monitoring was carried out using Campbell Scientific CR10X programmable dataloggers to record hourly averages of light, relative humidity, and air temperature (at seedling

height), surface temperature, and soil temperature and soil moisture at –15 cm from a profile immediately adjacent to representative seedlings in each type of planting microsite. Four sensor profiles (one from each microsite type) were connected to each datalogger. These were installed in each of the clearcut, 50% and 75% residual compartments in one replicate of the two forest types (aspen-dominated in area A, and conifer-dominated in area G on the site map; Fig. 1). The spatial range of variation in microclimate was assessed by manual spot measurements at marked locations in all three replicates of each forest type (18 silviculture plots). Three spots were located in each quadrant of each silviculture plot (one of which was the automated sensor profile where they existed). A thermocouple was buried at –15 cm at each spot, and used to measure soil temperature along with measurements of air and surface temperature on two dates (27 August and 17 October).

Growing degree-days (GDD) are a way of summarizing the temperature regime in a way that is relevant to plant growth. We calculated GDD(air) by summing the hourly average air temperatures above 0 °C for each month and dividing by 24 to put the values on a daily basis.

Post site preparation assessments to classify the final microsite profiles and measure root collar diameter (RCD) and height of the seedlings were carried out by Derek Sidders (CFS) in collaboration with CanFor Hines Creek. Long-term monitoring of planted stock growth response in years 2, 5, and 10 will include field measurement of height and RCD, and will be carried out under the auspices of a separate project. Subsample harvesting for biomass accumulation and partitioning to needles, stems, and roots will also take place in those years as part of the current proposed project.

*Effect of partial harvesting and mechanical site preparation on regeneration by seed*

A further 40 pinned microsites per quadrant were operationally seeded in September with 100 viable seeds per microsite from a local bulk seed collection. These microsites will be used for long-term monitoring of establishment and survival in an operational seeding context. Another 48 microsites per quadrant were pinned and flagged for the seedbed longevity study to be initiated next spring. One group of 8 microsites will be left for assessing regeneration from natural seed rain. Another group of 8 will be seeded in spring 2000, and the remaining groups in alternate years until 2008. Long-term viability of the seedbed will be assessed by continuing annual counts of the germinants in the seeding plots beginning in fall 2000. Each cohort (year-class) will be monitored for four years, so that no more than three cohorts will be counted in any one year.

In cases where there were fewer than 198 microsites available, the number of microsites marked for the seedbed study and operational seeding were reduced.

To accurately assess the seeding trials, the white spruce seed rain was monitored by placing seed traps in each silviculture plot. Four seed traps were located around each silviculture plot, one on each of the north, south, east and west boundaries. In addition, we are collaborating with Dr. Dan Gilmore who is studying regeneration of other species. We are able to count the white spruce seed in his traps (total 58 in uncut controls in aspen- and conifer-dominated and mixedwood forest types, and clearcut, 50% and 75% residual treatments in the mixedwood sites). In return, we provide our seed trap samples to him to analyze the other species.

*Development of cone crop potential following release*

The development of a procedure to measure cone crops involved three stages. The slowest but most accurate method of measuring cone crops is to fell the trees and collect every cone for counting. This can only reasonably be done for a small subsample of trees. Faster and less accurate is to count cones from the ground using binoculars and viewing from only one side of the tree (SE to SW aspect). This method is still too slow to use for samples of hundreds of trees, but provides a bridge to the quickest method, which is to model from estimated indices of cone and crown density combined with the length of cone-bearing crown.

To acquire the appropriate data for these three stages, white spruce trees in all crown classes were examined in the windthrow transects in each residual type of the conifer-dominated forest type. These transects were 10 m wide and ran perpendicular to the machine corridors across the widest part of the compartment. In the uncut controls, trees in the productivity tree plots were examined. Height, height to live crown, height to cones, and diameter of the selected trees were measured, as well as the crown density and cone density being rated for each tree. We calibrated this rating system using both visual ground-based counts using binoculars, and by counting every cone on felled trees from the edges of the study stands. Photographs of the crown were taken, and used in developing the cone crop models. The development of a system for measuring cone crops from analysis of digitized photographs was not begun due to insufficient resources.

*Study Schedule*

| Task | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2008 | 2009 |
|---|---|---|---|---|---|---|---|---|---|---|
| Year | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 10 |
| Seedbed study seeding (spring) | | * | | * | | * | | * | | |
| Fall count of germinants | | * | * | * | * | * | * | * | * | * |
| Seedling heights & diameter | * | * | * | | | * | | | | * |
| Seedling physiology measurements | | * | * | | | * | | | | * |
| Harvest seedlings for biomass | * | * | * | | | * | | | | * |
| Seedling microenvironment measurements | * | * | * | | | * | | | | * |
| Measure windthrow | * | * | * | * | * | * | | | | |
| Measure cone crop | * | * | * | * | * | * | * | * | | |
| Measure seed rain | * | * | * | * | * | * | * | * | * | * |

## Results and Discussion

*Effect of partial harvesting and mechanical site preparation on growth of planted stock*

There were no significant differences in seedling size among the different harvest treatments or site preparation treatments, with the single exception of height being significantly less in the mixed treatment compared to the other site preparation treatments (Table 1). Save the noted exception, the results indicate that there was no bias in planting out the seedlings among the different treatments. It was not expected that the seedlings would grow enough in the first year to reflect the environments of the different experimental treatments. These values will be used as the basis for all future calculation of growth rate in the planted stock.

Table 1. Seedling height, root collar diameter, and dry weights from 415B white spruce stock planted in the EMEND silviculture plots.

| Variable | Mean | SE |
|---|---|---|
| Height (cm; mixed treatment) | 19.9 | 0.66 |
| Height (cm; all other treatments) | 22.7 | 0.47 |
| RCD (mm) | 2.96 | 0.056 |
| Leaf DWt (g) | 1.07 | 0.041 |
| Stem DWt (g) | 0.858 | 0.038 |
| Root DWt (g) | 0.728 | 0.057 |

The nutrient analysis results showed that there were no significant differences in needle nitrogen concentration among seedlings from the different forest types, harvest and site preparation treatments (Table 2). However, there was significantly less phosphorus in the needles of seedlings from the aspen-dominated stands than from the conifer-dominated stands, although there were no differences in P concentration among the different treatments. These data will provide a baseline from which to assess the uptake or loss of nutrients as the seedlings grow and respond to their microenvironmental conditions.

Table 2. Nitrogen and phosphorus concentrations in the needles of white spruce seedlings planted under different residual canopy densities and microsites in aspen- and conifer-dominated stands.

| Variable | Mean | SE |
|---|---|---|
| Needle N concentration (% dwt) | 1.82 | 0.054 |
| Adom needle P conc. (mg/g dwt) | 2.31 | 0.081 |
| Cdom needle P conc. (mg/g dwt) | 2.64 | 0.118 |

Microclimate data as presented here represents time series data from single sensors for each variable (e.g., light, and temperature) in each combination of forest type, harvest and site preparation treatments. Until corroborated by more time series data and extensive spot measurements over a broader spatial range, these results should be treated as being very

preliminary. Freezing rain on a solar panel combined with a weak battery caused a power outage in the Conifer 50% station resulting in a loss of data from September 15 until November 15. Despite these constraints, our microclimate data showed some interesting differences among the sites and treatments.

Our light data for the aspen stands show that seedlings planted in the 50% harvest treatment received between 40% and 70% of the sunlight that their counterparts in the clearcut received (Fig. 6). The seedlings in the aspen 75% compartment received between 10% and 30% of the light in clearcuts during the summer and between 20% and 35% in the fall. Seedlings in both partial cuts received about 10% more light in the fall after the aspen had lost their leaves. The increase was not greater than this because the sun stayed lower in the sky and shading by the stems had a greater effect than in summer.

The results were very different for the conifer stands. Since there was no significant leaf loss in the fall, light diminished steadily during the entire recording period (Fig. 6). The average light transmission to the understory in the 75% compartment was about 30% at the end of July and diminished to less than 5% by the middle of November. The 50% harvest treatment rarely allowed more than an additional 15% more light at seedling height compared with the 75% treatment.

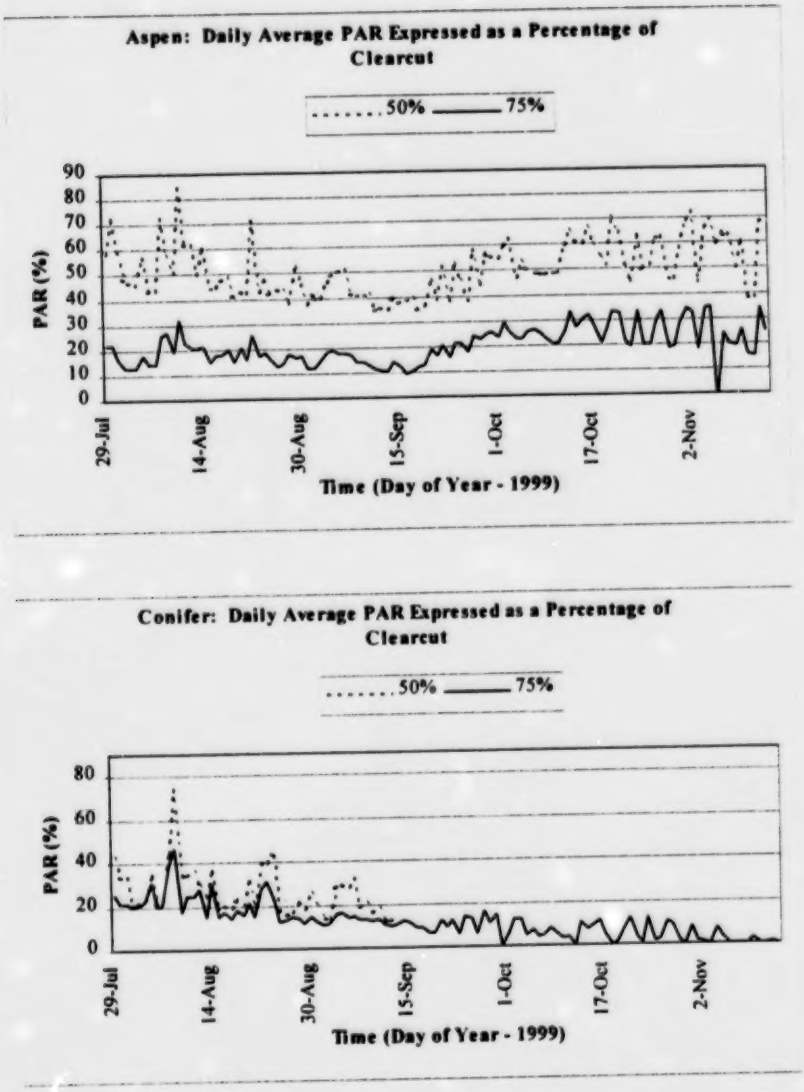


Figure 6. Light regime at seedling height of the partial-cut compartments expressed as a percentage of full sunlight as measured in the neighboring clearcut compartments.

The threshold for maximum height growth in white spruce is about 40% of full sunlight (Lieffers and Stadt 1994). It appears that, at least in the first year after harvest, the light regime under a 50% residual aspen canopy is more than sufficient to support maximum growth of our planted seedlings. However, light was a limiting factor in the conifer 50% treatment as well as in both aspen and conifer 75% treatments.

As with light, there is a strong contrast in the relative humidity (RH) regimes between the aspen and conifer stands (Fig. 7). In the aspen stands, RH in the 50% residual was very similar to that in the clearcut, while the 75% residual had much lower minimum humidities. In the conifer stands, there was a consistent gradient of minimum RH from the most humid in the 75% to the

least humid in the clearcut. Low humidity, especially when combined with high light levels, can cause stomata on the needles to close, limiting photosynthesis and, over time, reducing growth of the seedlings (Marsden et al. 1996).

Although we have confidence in the relative trends presented here for RH, the absolute values of humidity, particularly at the low end, may not be accurate. A program of calibration is being planned for this field season to address this issue.

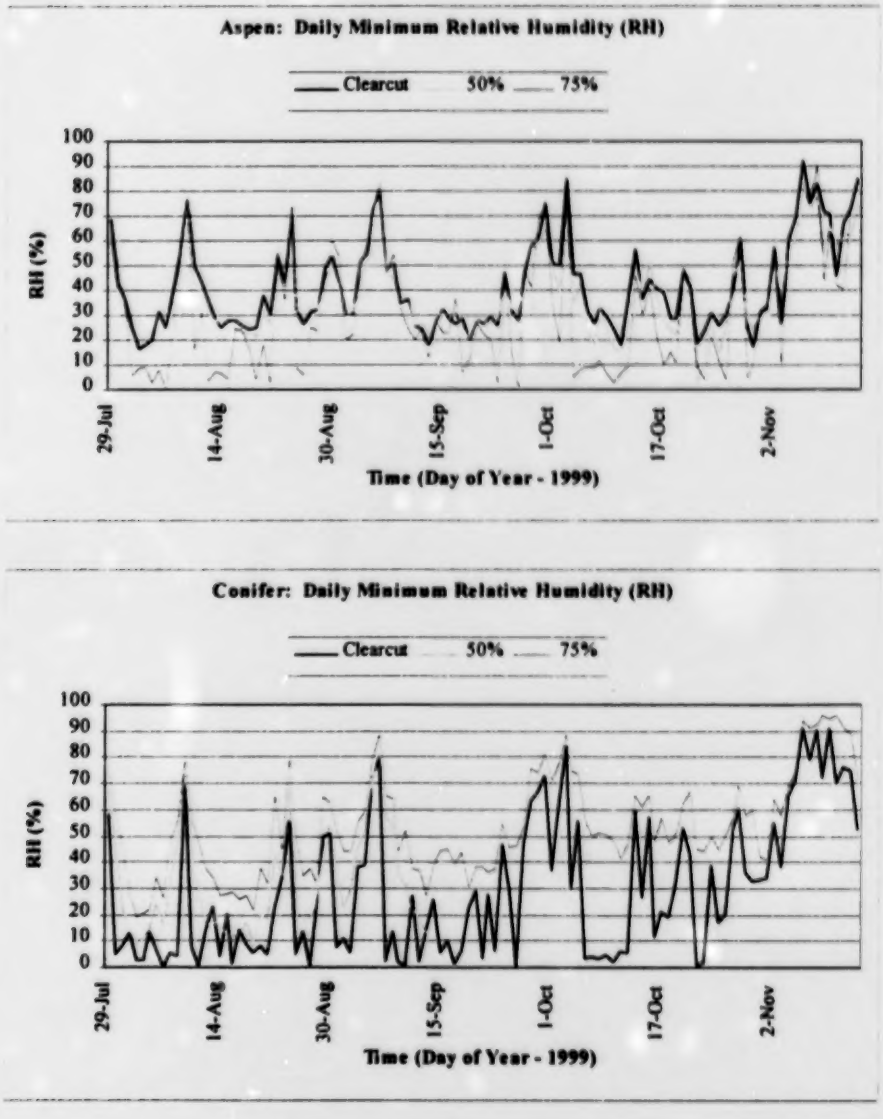


Figure 7. Daily minimum relative humidity measured at seedling height in different harvesting treatments in aspen and conifer stands.

Air temperature at seedling height did not differ much between the different harvest residual densities in the conifer stands, although occasionally the clearcut was warmer than the two partial-cut treatments (Fig 8). The differences among harvest treatments were greater and more consistent in the aspen stands, exhibiting a consistent gradient from coolest in the 75% residual to warmest in the clearcut. In the boreal forest, which is characterized by cool temperatures, the warmer the temperature the better for growth.

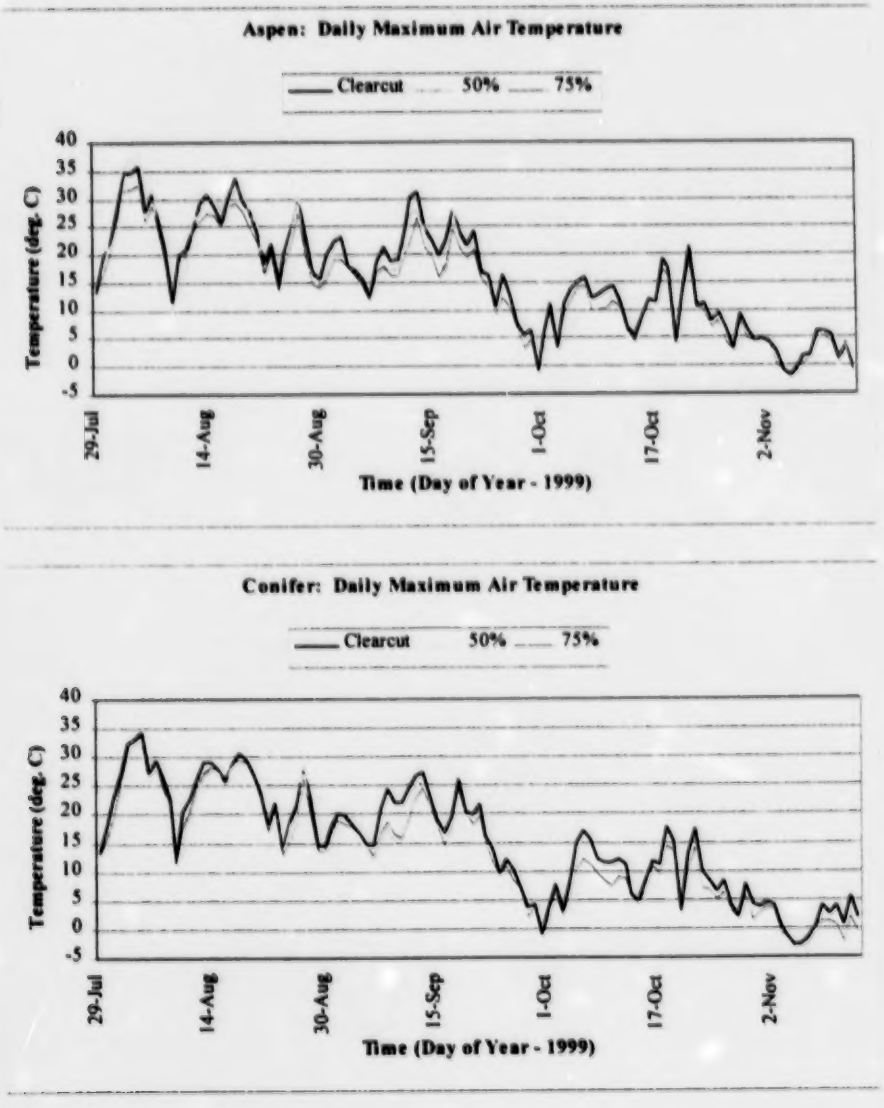


Figure 8. A daily maximum air temperature at seedling height in different harvesting treatments in aspen and conifer stands.

Minimum air temperatures show the onset of frost events and conditions limiting to growth (Fig. 9). Spruce seedlings can photosynthesize at temperatures at 5 °C (Man and Lieffers 1998), but growth is limited by low temperatures. Although it is not entirely consistent, there is a general trend of minimum temperatures being lower as the residual tree density decreases.

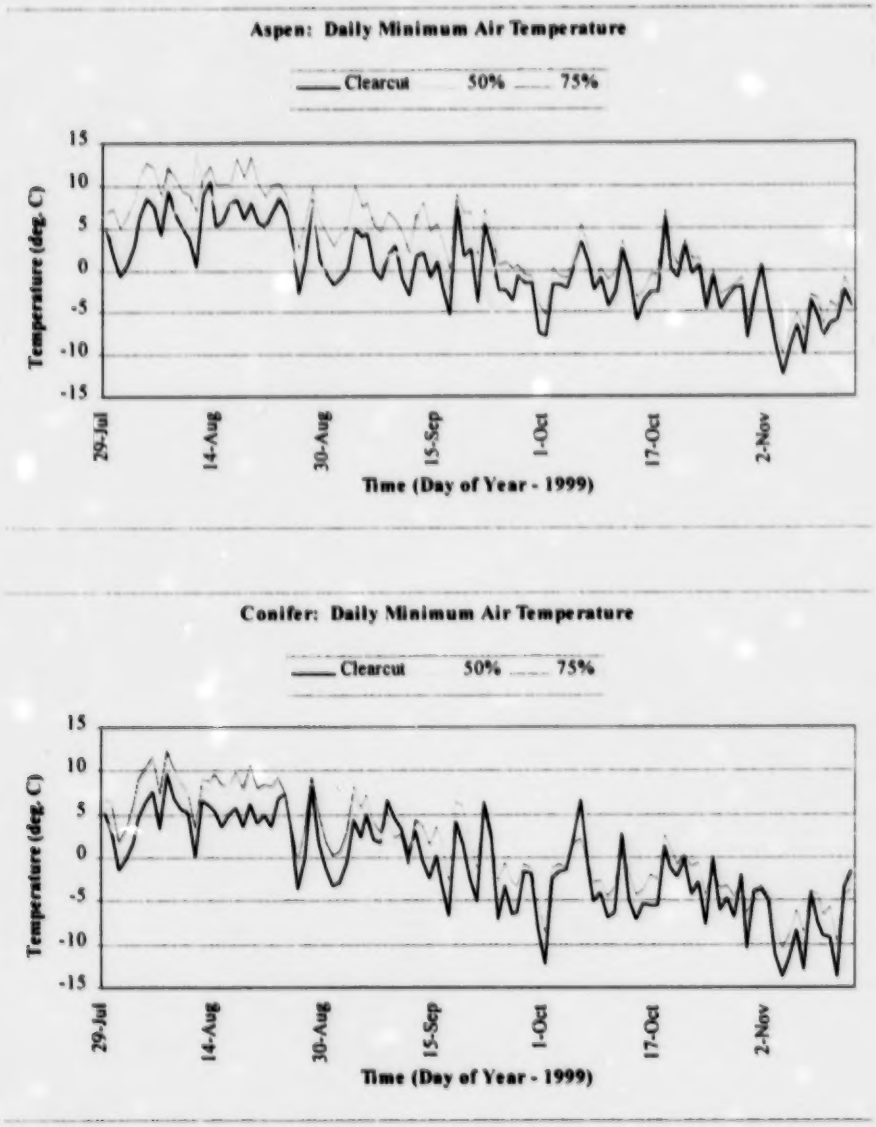


Figure 9. A daily minimum air temperature at seedling height in different harvesting treatments in aspen and conifer stands.

The accumulated effect of even minor temperature differences can be assessed by examining growing degree-days. Given no other limitations to growth, e.g., light, water or nutrients, GDD represents the growing potential during each time period. During daylight hours, photosynthesis responds to air temperature, and at night, growth respiration is affected by temperature. In a similar manner, GDD(soil) was calculated to summarize the heat regime in the root environment, using data from the –15 cm temperature data. Uptake of water and nutrients by roots is affected by temperature. There appears to be little difference in growing degree-days based on air temperature (GGD(air)) between Adom and Cdom clearcuts (Fig. 10). However, the Cdom 75% residual site is consistently cooler than the corresponding Adom site. For the 50% residuals, the Cdom site was warmer in August and in the first part of September (144 GDD vs 123 GDD for the Aspen site) when data was available. These differences are likely due to the increased shading cooling temperatures during the day, and slowing radiative heat loss at night. No shade in the clearcut means that there will be little difference in microclimate other than that driven by surface characteristics. In the 75% residual, there is enough shade to keep temperatures low, even with the extra heat-trapping properties of the tree crowns. The increasing difference between the Cdom and Adom sites with 75% residual later in the year supports this hypothesis since the leafless aspen allow more ground heating in the fall than in conifer sites. Overall, the Adom 75% treatment provided the most GGDs in each month, and Adom 50% the least.

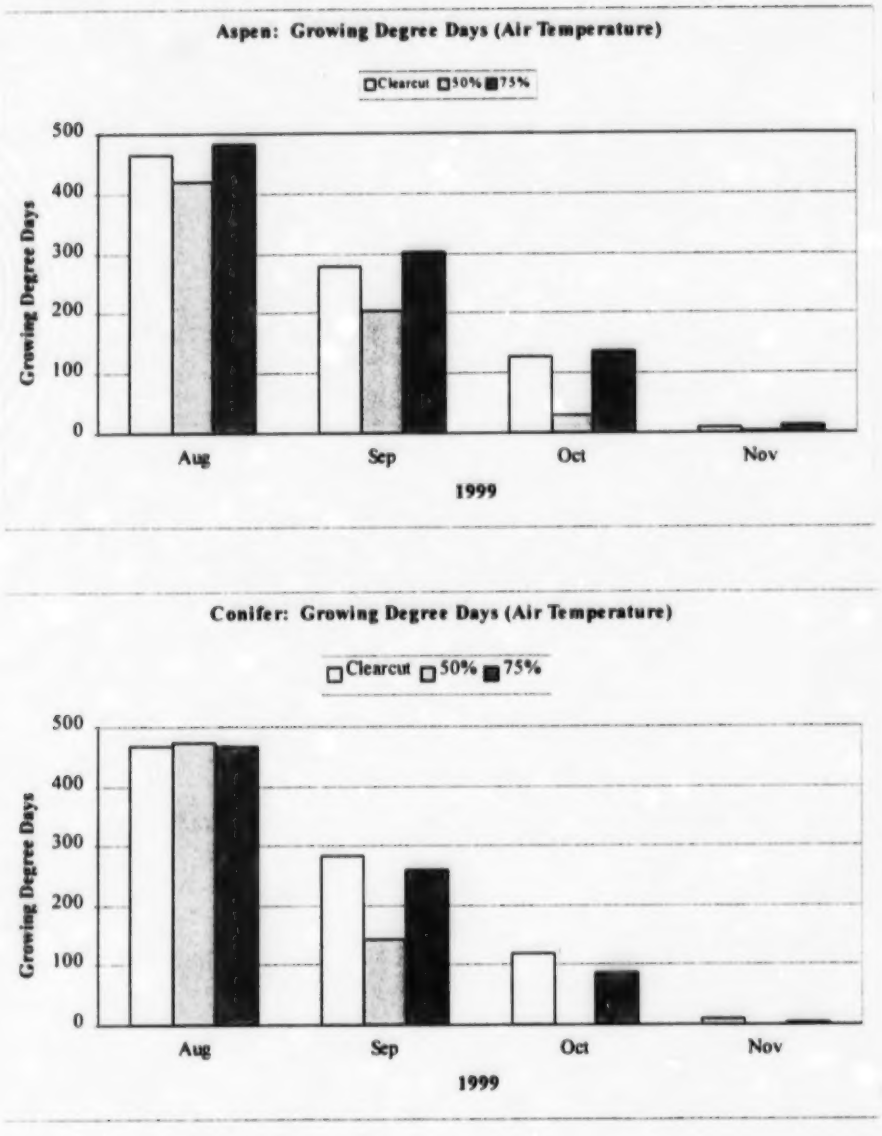


Figure 10. Growing degree-days for seedling height air temperature in different harvesting treatments in aspen and conifer stands. Note: the conifer 50% data was collected up to and including September 14th.

Another measure of the suitability for growth of seedlings is the number of frost days. Although there appeared to be more frost events in the conifer clearcut than the aspen clearcut, no significant differences between the forest types are apparent for the two partial-cut treatments (Table 3). There also were fewer frost events in the 50% aspen compartment than in the 75% or clearcut, which is in apparent contradiction with the GGD analysis discussed above.

Table 3. Frost occurrence in the different harvest residual treatments in aspen- and conifer-dominated sites. November data is for the first 15 days only.

| Harvesting Treatment | | August | September | October | November |
|---|---|---|---|---|---|
| ***Aspen*** | Clear Cut | 2 | 8 | 13 | 8 |
| | 50% Residual | 0 | 2 | 18 | 14 |
| | 75% Residual | 3 | 15 | 23 | 14 |
| ***Conifer*** | Clear Cut | 5 | 15 | 27 | 14 |
| | 50% Residual | 0 | 1 | | |
| | 75% Residual | 1 | 9 | 25 | 15 |

Soil temperatures show a few consistent trends (Table 4). Summer temperatures under mounds were the warmest and the most variable, while under undisturbed forest floor (control) summer temperatures were the coolest and least variable. In the fall, soils cooled down, but less so in the controls than in the other treatments. Treatments with exposed mineral soils (mounds and scrapes) cooled the most and the mixed treatment was intermediate. In the aspen compartments, temperature maxima and variability decreased as the amount of residual canopy increased. There was no distinct trend with residual in the conifer compartments. In general, soils under aspen were cooler and less variable, but there were exceptions, particularly in the conifer 50% compartment.

The spatial replicate soil temperature data (spot measurements) show a relatively low degree of variation (based on standard error values in Table 4), especially considering these measurements were not simultaneous, but taken over a 3-hour span for each forest type. As we saw from the datalogger time series data, soil temperature was affected by the composition of the surface layer. Mound and scrape soil temperatures were lower than mix or control temperatures in the aspen compartments in both the August and October readings. This trend also was apparent in the conifer compartments in October, but the reverse trend was observed in August. The next step in processing these data is to make time-specific connections to the datalogger data, and quantify any consistent lags or offsets between the spot and time series datasets.

Surface temperatures were the most difficult to measure accurately, and we are still working to verify the results from these sensors. Preliminary data show this to be a more variable factor than –15 cm soil temperature, as we expected (Table 5). It is difficult to distinguish a pattern in these results, and we will need to increase the number of spatial replicates that we measure, and make use of other technology (namely an infrared thermometer) to adequately capture the real pattern of variation in this microclimate variable.

Table 4. Summary of -15 cm soil temperatures from the four site prep and two harvesting treatments at EMEND.

| Harvesting Treatment | Site Prep Treatment | August 1999 -15 cm Soil Temperature (C°) Mean | August 1999 -15 cm Soil Temperature (C°) SE | October 1999 -15 cm Soil Temperature (C°) Mean | October 1999 -15 cm Soil Temperature (C°) SE |
|---|---|---|---|---|---|
| ***Aspen dominated site*** | | | | | |
| Clear cut | Control | 10.11 | 0.13 | 4.70 | 0.31 |
| | Mix | 11.41 | 0.32 | 4.51 | 0.43 |
| | Mound | 7.75 | 0.59 | 2.26 | 0.54 |
| | Scrape | 9.39 | 0.36 | 3.08 | 0.38 |
| 50% Residual | Control | 10.14 | 0.45 | 4.55 | 0.22 |
| | Mix | 11.20 | 0.31 | 4.57 | 0.30 |
| | Mound | 9.60 | 0.71 | 2.20 | 0.29 |
| | Scrape | 9.81 | 0.52 | 3.24 | 0.34 |
| 75% Residual | Control | 10.40 | 0.44 | 5.16 | 0.30 |
| | Mix | 10.43 | 0.35 | 3.80 | 0.25 |
| | Mound | 9.89 | 0.32 | 2.89 | 0.55 |
| | Scrape | 9.42 | 0.40 | 3.03 | 0.23 |
| ***Conifer dominated site*** | | | | | |
| Clear cut | Control | 10.98 | 0.36 | 4.25 | 0.37 |
| | Mix | 11.06 | 0.36 | 4.06 | 0.39 |
| | Mound | 11.30 | 0.44 | 2.40 | 0.45 |
| | Scrape | 11.52 | 0.33 | 3.41 | 0.32 |
| 50% Residual | Control | 9.13 | 0.31 | 4.31 | 0.19 |
| | Mix | 9.99 | 0.40 | 4.30 | 0.12 |
| | Mound | 10.43 | 0.46 | 2.89 | 0.30 |
| | Scrape | 10.86 | 0.20 | 3.28 | 0.08 |
| 75% Residual | Control | 9.16 | 0.25 | 5.10 | 0.23 |
| | Mix | 9.27 | 0.17 | 4.50 | 0.65 |
| | Mound | 9.87 | 0.27 | 2.57 | 0.42 |
| | Scrape | 9.55 | 0.24 | 3.59 | 0.47 |

Table 5. Summary of surface soil temperature at EMEND.

| Harvesting Treatment | Site Prep Treatment | August 1999 Soil Surface Temperature (C°) | | October 1999 Soil Surface Temperature (C°) | |
|---|---|---|---|---|---|
| | | Mean | SE | Mean | SE |
| ***Aspen dominated*** | | | | | |
| Clear cut | Control | 8.31 | | 3.56 | 0.57 |
| | Mix | 19.69 | | 4.69 | 1.11 |
| | Mound | 22.11 | | 4.72 | 1.40 |
| | Scrape | 15.02 | 1.80 | 3.80 | 0.76 |
| 50% Residual | Control | 14.91 | | 4.63 | 0.73 |
| | Mix | 11.41 | 0.70 | 4.54 | 0.54 |
| | Mound | 17.01 | 1.41 | 3.66 | 0.66 |
| | Scrape | 11.83 | | 4.47 | 0.50 |
| 75% Residual | Control | 13.89 | | 3.59 | 0.31 |
| | Mix | 14.91 | | 1.72 | 0.39 |
| | Mound | 10.63 | 0.20 | 1.83 | 0.38 |
| | Scrape | 7.63 | 0.01 | 1.90 | 0.33 |
| ***Conifer dominated*** | | | | | |
| Clear cut | Control | 11.82 | | 1.81 | 0.83 |
| | Mix | 16.16 | | 2.49 | 0.98 |
| | Mound | 8.82 | | 1.62 | 0.80 |
| | Scrape | 13.93 | | 2.68 | 0.57 |
| 50% Residual | Control | 20.18 | | 5.44 | 0.71 |
| | Mix | 9.95 | | 5.38 | 0.42 |
| | Mound | 13.17 | | 4.85 | 0.69 |
| | Scrape | 7.63 | | 4.70 | 0.33 |
| 75% Residual | Control | 10.69 | | 5.93 | 0.50 |
| | Mix | 6.81 | | 3.85 | 0.69 |
| | Mound | 10.96 | | 3.93 | 0.38 |
| | Scrape | 12.44 | | 5.08 | 0.38 |

Growing degree-days measured in the soil are more complicated to interpret than GDD from air temperature, because they are influenced by the site preparation microsite conditions. Taken separately, the trends among site treatments differ in the Adom and Cdom sites (Table 6). For conifer sites, control (untreated) microsites were coolest in the clearcut and 50% treatments during the summer. In the 75% treatment, it was the mix treatment that was coolest. Mounds and scrapes were the warmest microsites in the summer. In the fall, the mounds were consistently the coolest, and controls the warmest. Here it appears that the insulating properties of the forest floor organic layers are important, keeping the soil cool in summer and warm in the fall. In the Adom sites, control microsites were again the coolest, and scrapes were consistently the coolest in the fall. The warmest spots were the mix and mound microsites. More data is required to verify these results.

Table 6. Growing degree-days (soil) for the harvesting treatments in aspen and conifer stands.

| Site Prep. | August | September | October | November |
|---|---|---|---|---|
| ***Aspen Clear Cut*** | | | | |
| Control | 354 | 298 | 211 | 72 |
| Mound | 522 | 359 | 165 | 34 |
| Scrape | 412 | 267 | 102 | 20 |
| Mix | 470 | 404 | 261 | 84 |
| ***Aspen 50% Residual*** | | | | |
| Control | 300 | 232 | 117 | 11 |
| Mound | 380 | 265 | 99 | 1 |
| Scrape | 356 | 212 | 55 | 0 |
| Mix | 404 | 293 | 142 | 17 |
| ***Aspen 75% Residual*** | | | | |
| Control | 317 | 252 | 162 | 50 |
| Mound | 395 | 311 | 173 | 52 |
| Scrape | 341 | 219 | 73 | 4 |
| Mix | 398 | 291 | 150 | 34 |
| ***Conifer Clear Cut*** | | | | |
| Control | 333 | 283 | 179 | 53 |
| Mound | 443 | 242 | 46 | 0 |
| Scrape | 463 | 323 | 157 | 34 |
| Mix | 373 | 245 | 82 | 0 |
| ***Conifer 50% Residual*** | | | | |
| Control | 265 | 112 | | |
| Mound | 464 | 158 | | |
| Scrape | 439 | 160 | | |
| Mix | 284 | 104 | | |
| ***Conifer 75% Residual*** | | | | |
| Control | 313 | 272 | 192 | 65 |
| Mound | 350 | 109 | 39 | 0 |
| Scrape | 302 | 202 | 63 | 5 |
| Mix | 285 | 202 | 88 | 9 |

Soil moisture in Figure 11 is presented as soil water tension. As the soil dries, the remaining water is held more tightly, giving higher tension values. The data from the sensors in the clearcuts, and from the control microsites in all compartments are not presented because of quality control issues that need to be resolved. The data from scrape and mix in the 75% treatments are shown as examples. From the results that are presented, it can be seen that soil moisture even at a relatively shallow depth changes very little over the growing season, other than a slight drying trend. All of the variation shown in the graph represents small changes in soil water availability. The tension values were always in the range of mild water stress that would have had a correspondingly small limiting effect on seedling growth. A spatially extensive program of spot measurements is planned for the next few field seasons to more accurately represent microsite effects on soil moisture and determine whether the results from the datalogger stations represent typical conditions across the study area.

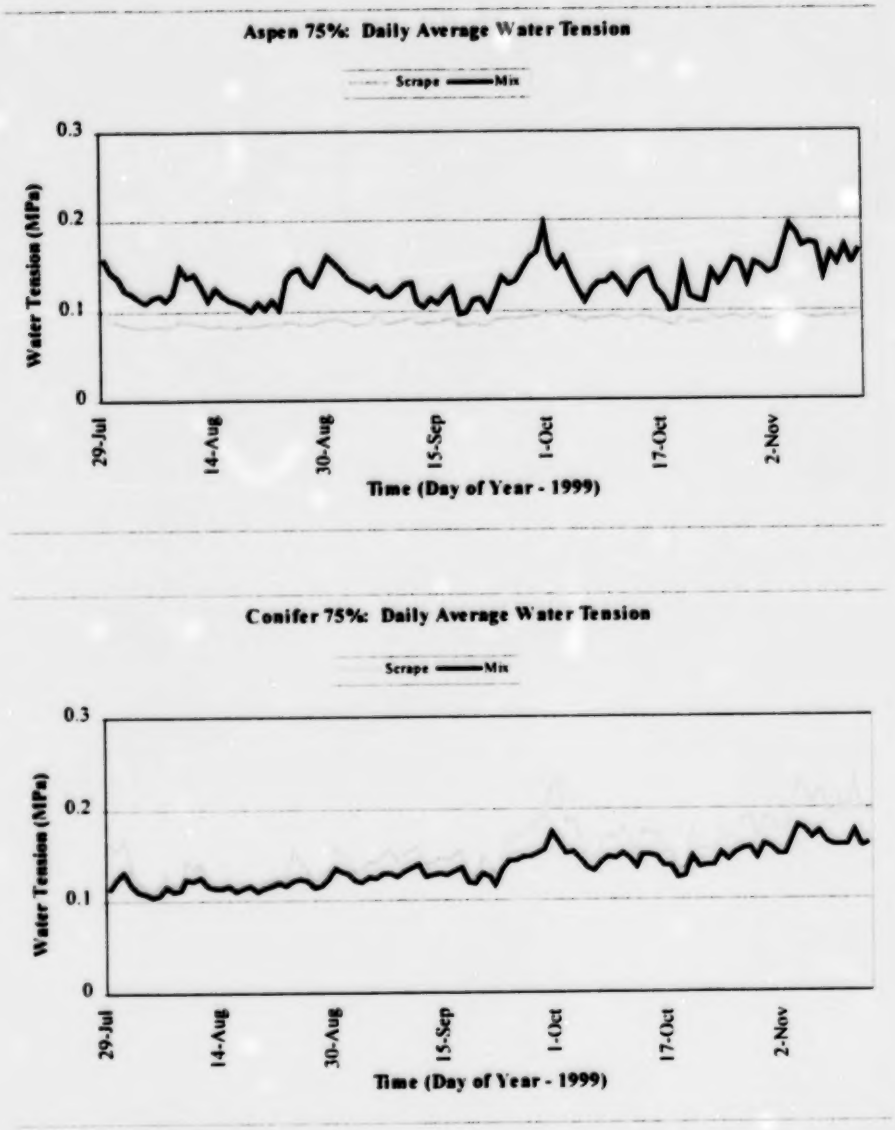


Figure 11. Daily mean soil water tension –15 cm for four different microsite types in different harvesting treatments in aspen and conifer stands.

The air and soil microclimate measurements will be part of the experiment-wide microclimate monitoring network on the EMEND site. Meetings are being held to organize whatever linkages are possible among the different studies that measure aspects of atmospheric and soil microclimate. This will allow all EMEND researchers to take advantage of measurements being taken at different spatial and temporal scales which will provide a broader context for our research results.

*Effect of partial harvesting and mechanical site preparation on regeneration by seed*

As seeding was only carried out this fall, counts of germinants will commence next year. The seedbed viability study will have its initial seeding take place in spring of 2000.

The white spruce seed rain was measured in seed traps placed in each silviculture plot (Table 7). In the aspen-dominated stands, the white spruce seeds we found in our traps would have come from the few spruce mixed into the stand and from spruce outside the stand. The fact that the number of seeds did not increase consistently with residual density suggests that sources outside the compartment did have a small but significant effect. In comparing the Adom and Cdom clearcuts, it can be seen that the seed rain into the Cdom clearcut was influenced by the surrounding spruce stands. The seed rain scaled closely with the residual density, as seed rain in the Cdom 50% compartment was only slightly more than two-thirds that in the 75% compartment. The seed rain values for the mixedwood stands were, as expected, intermediate between those for Adom and Cdom stands. However, the 50% mixedwood stands had a greater seed rain than the 50 % Cdom stands. The reason for this is not clear.

Table 7. The mean and standard error of white spruce seeds landing in the different forest types and harvest treatments of the EMEND experiment.

| | Adom | Mixedwood | Cdom |
|---|---|---|---|
| **Harvesting Treatment** | **Mean (SE) Seeds/$m^2$** | **Mean (SE) Seeds/$m^2$** | **Mean (SE) Seeds/$m^2$** |
| Clear cut | 54.5 (19.09) | | 221 (34.2) |
| 50% residual | 33.3 (8.67) | 2183 (429.1) | 1880 (218.5) |
| 75% residual | 266 (99.3) | 2207 (357.4) | 2322 (229.8) |
| Uncut control | 360 (116.9) | 2567 (1165.5) | 3136 (692.9) |

Viability of seed from felled trees and from seed traps is being assessed in collaboration with Dr. Dan Gilmore.

*Development of cone crop potential following release*

The calibration of our ground-measured cone counts was based on 12 trees that were felled to allow an accurate count of every cone. These trees were selected to represent the range of size, cone density and crown density found in the study stands. Figure 12 shows that ground-based counts underestimated the actual number of cones, but an accurate estimate could be calculated using the following regression model.

$$\text{adjusted cone number} = 6.889 * \text{ground count} \qquad \text{eqn. 1}$$

This model was then used in the next step of calibrating the indices that were recorded for each tree in the sample transects.

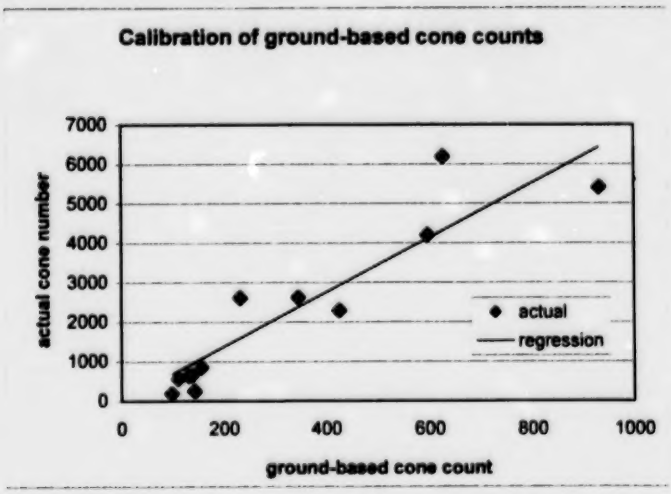


Figure 12. Calibration of ground-based cone counts with actual cone numbers from felled white spruce trees.

The next stage was to use the ground-based estimates from the subsample of trees in the transects for which this was recorded, and calculate the real number of cones using our regression relationship. Then a model was constructed using the length of the tree crown that bore cones, a relative index of cone density (on a scale of 0 to 5) and another relative index of crown form and density (again from 0 to 5). The model was based on calculating the cone-bearing surface area of the individual tree using the geometric function describing the surface area of a cone. The cone-bearing length of crown for each tree was measured using a hypsometer. The apex angle of the cone (35°) was the average measured from photographs taken of a subset of the trees for which ground-based counts were made. This surface area was then multiplied by the cone and crown indices to produce a relative cone crop measure. This value was regressed against our adjusted cone number to estimate the density parameter in the following model.

$$realcone=pi*0.7*d*L*CDI*CFI*sqrt(length^2(1.7^2))/25 \qquad \text{eqn. 2}$$

where d is the cone density parameter, 0.7 is tan (35°), L is the cone-bearing crown length, CDI is the cone density index, and CFI is the crown form index. The parameter d was determined to be 91.95, with an $R^2$ of 0.67 for the model.

There were a number of trees for which the cone crop model fit poorly (Fig. 13). This may be due to differences in tree form or cone size. There may be distinct populations of trees that have different cone crop characteristics. Modification of our model to incorporate data on tree size and shape may improve the accuracy of our predictions.

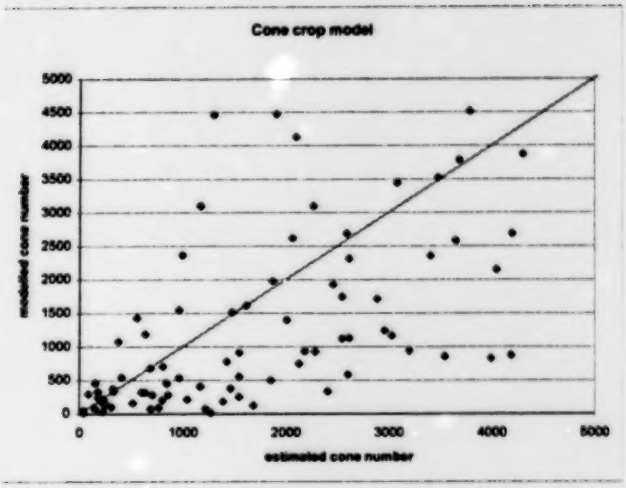


Figure 13. Comparison of modelled cone number and cone number estimated from ground-based counts. Solid line is the 1:1 line.

One variable that may be affecting the fit of the model is difference in cone size. There is a two-fold range in cone length and in number of scales, and a four-fold range in cone dry weight in our sample (Fig. 14). This variation in size may account for much of the differences between estimates from ground-based counts and the modelled results derived from cone and crown density indices seen in Fig. 13.

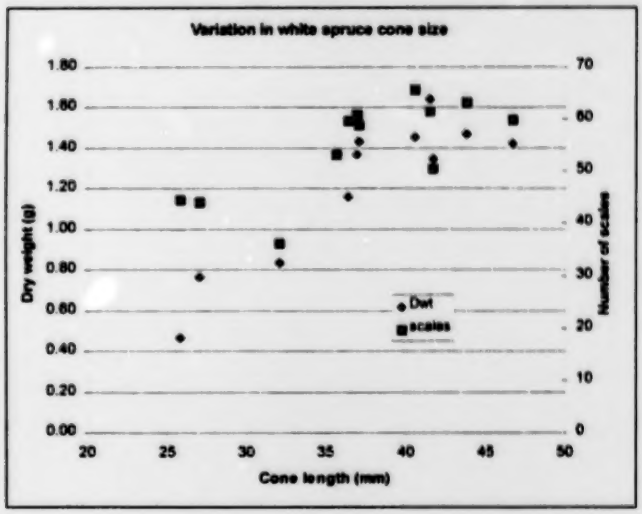


Figure 14. Comparison of cone dry weight and number of scales to cone length. Cones were harvested from the felled tree subsample.

Although both dry weight and number of cone scales increase as the length of the cone increases, there is variation in these relationships that may ultimately limit the precision with which we can calculate cone crops and seed production.

The estimated cone crop from our transect data increased proportionally with harvest residual up to 50%, but there was no difference between 50% and 75% residual treatments (Fig. 15). It appears that in the highest residual treatment, the production of cones may have been constrained by the density of the stand. Calculation of cone crops in the uncut controls is pending the establishment of a formal protocol for data sharing among EMEND researchers. These estimates will be included in future reports.

The comparison of seed rain with the estimate of cones produced in the different Cdom compartments gave seed:cone ratios ranging from 148 to 768, with a mean of 380 (SD 197). This spread of values is expected to narrow as the cone crop evaluation procedure is refined. As it stands now, we have a first approximation model, albeit somewhat crude, that can estimate seed rain from easily acquired stand data. This model now needs refinement in the cone crop sub-model, and expansion to account for year-to-year variation. Linking this model to the relationships we will develop from our work on natural regeneration establishment and survival will provide a quantitative prediction system for assessing the potential for natural white spruce regeneration in mixedwood forests.

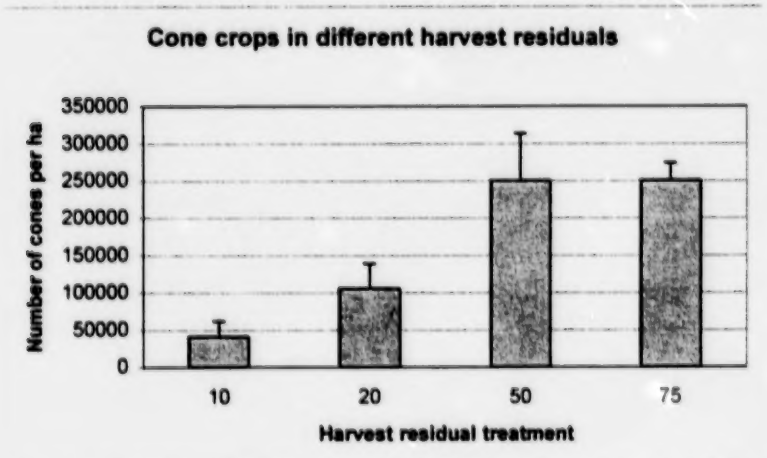


Figure 15. Cone crops produced in compartments with different residual densities of white spruce trees (error bars represent SE).

### *Conclusions and Recommendations*

The results presented in this report represent a very early stage in the proposed project, and therefore do not allow for any firm conclusions regarding the issues raised. However, we can use this preliminary data to identify places where measurements need to be refined or where holes exist in the overall design. We are also given glimpses of relationships that, if substantiated by our continued work, will provide greater insight into the silvicultural techniques that might be applied in partial-cut systems in boreal mixedwoods.

Although most of our results followed our expectations based on past experience and other studies, some results were not wholly anticipated. Examples of this is the interaction between forest type and harvest residual in air growing degree-days where Adom 75% was overall the warmest and Adom 50% the coolest environment for seedling growth. As well, there were distinct microclimate effects of the different microsite treatments and some interaction with harvest residual in soil temperature, and to a lesser extent in soil moisture. The seedlings appear to be responding quickly in their role as a bioassay of the microclimate conditions, with height differences showing up between site preparation treatments, and needle phosphorus concentrations differing between the two forest types. We expect the first few years after harvesting to exhibit the greatest changes in environment and seedling response, and have designed our measurement schedule and procedures to capture these changes.

A few modifications have been added to the work plan set out in the 1999 proposal. It became clear to us that the most appropriate place to do our cone crop study was in the windthrow transects that Derek Sidders was establishing. In helping him to set up and monitor these transects, we were able to reduce the effort required to measure tree characteristics and could increase the replication in our study. By contributing to the windthrow monitoring, we ensure continuity in long-term monitoring of stand stability and its impact on stand microclimate dynamics over the 10 years of our proposed study. Similarly, we are able to expand our seed rain study into mixedwood stands by collaborating with Dan Gilmore. By sharing the contents of our seed traps, both parties are able to increase the breadth of their respective studies, ours on white spruce, and his on all other species.

On-going discussions with other EMEND researchers who have an interest in microclimate are leading to establishment of a common protocol for measurements and identification of variables and locations where we have overlapping interests. Again, by defining our areas of shared interest, we all can benefit by either establishing a broader context for our interpretations and/or increasing the accuracy of our results. Collaborators in this scheme so far include Graham Hillman's hydrology group, Rick Hurdle, and Ivor Edwards. Thus far we have decided to augment the proposed study plan by increasing the number of spatial replicates of air, soil and surface temperatures and soil moisture (spot measurements), and relocating some to more closely match the pattern used by the hydrology group. In addition, more profiling stations will be added to help provide linkage between the data collected by us and that collected by other groups. It has also become apparent in our discussions that the forest floor may be playing a very significant role in modifying soil microclimate. To address this issue, we will be making measurements of forest floor depth along with other data, and consulting with Barb Kishchuk who has been collecting extensive data on forest floor as part of her soil studies across the EMEND experiment.

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